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5 Pollux Drive
Edwards AFB CA 93524-7048

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MEMORANDUM FOR PRR (In-House Presentation)

FROM: PROI (TI) (STINFO) 19 May 1999

SUBJECT: Authorization for Release of Technical Information, Control Number: AFRL-PR-ED-TP-FY99-0100
Dr Greg Ruderman, "Overview of AFRL Aging and Surveillance Programs"
On-Site presentation **(Statement A)**

Overview of AFRL Aging and Surveillance Programs

Prepared for:

University of Illinois

Center for the Simulation of Advanced Rockets

May 24-25, 1999

Gregory A. Ruderman
gregory_ruderman@ple.af.mil
Air Force Research Laboratory
Edwards AFB, CA

Aging and Surveillance
Summary of Goals and Payoffs

Goals:

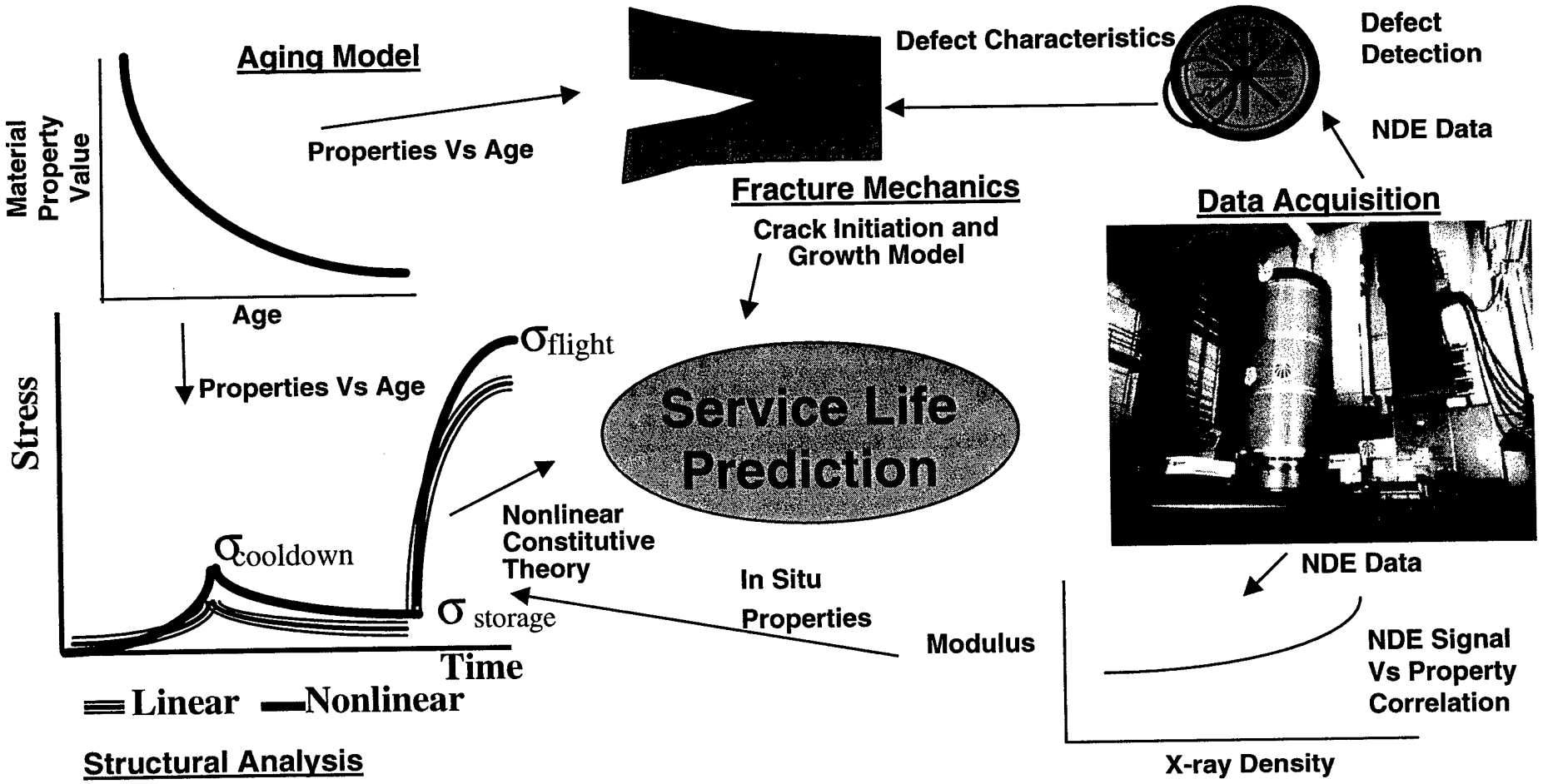
- **Enlarge Predictive Window of Visibility ("Look-Ahead Window") From 5 Years to 10 Years**
  - **Reduce Errors and Uncertainties in Analysis Processes**
- **Reduce Time and Cost for Performing Non-destructive (Inspection) Data Evaluation**

Payoffs:

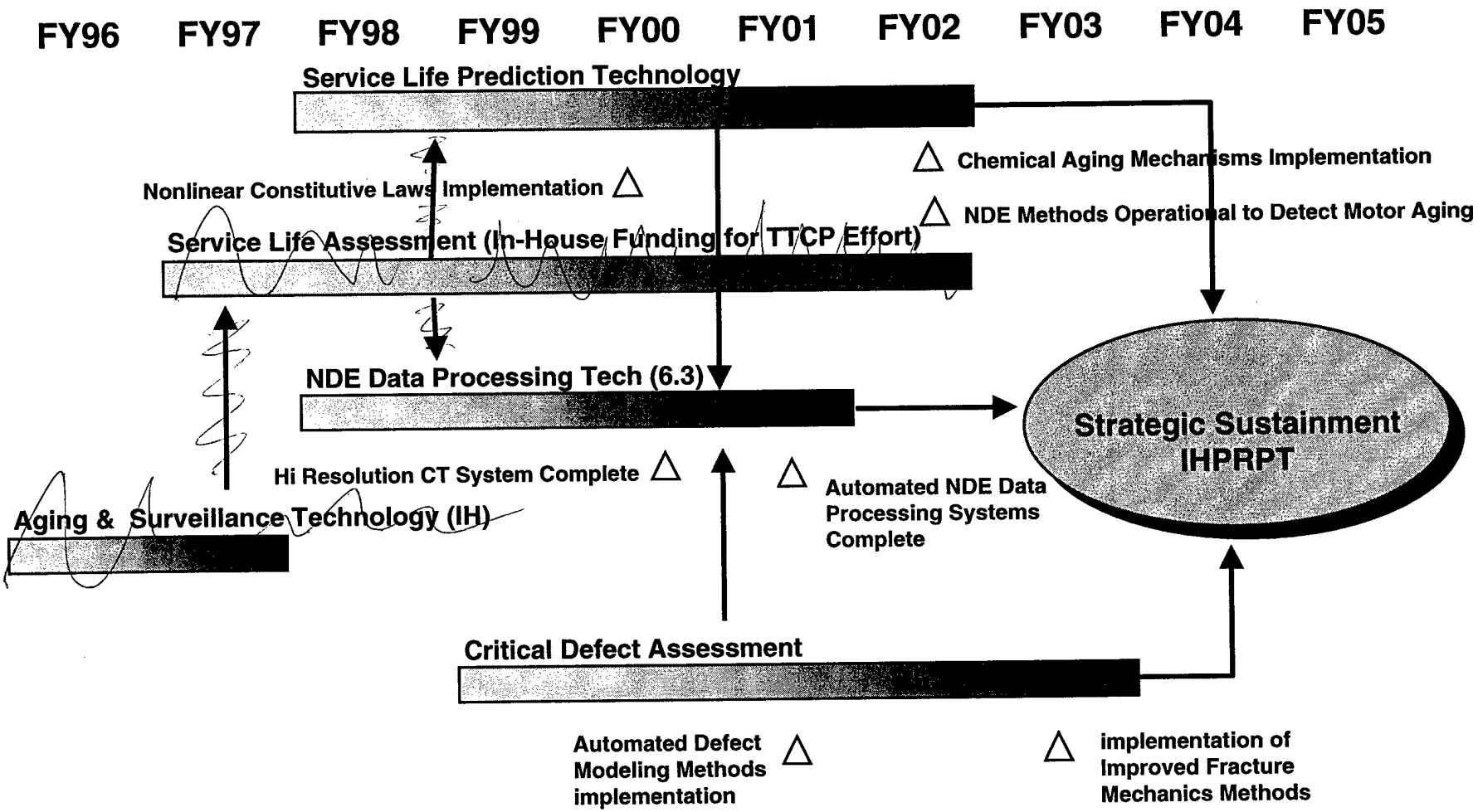
- **Maximize force availability by providing sufficient time to replace components if necessary**
- **Avoid unnecessary costs of premature replacement**
- **Technologies are applicable to all extended life systems: Air Force, Navy, Army, NASA**

Aging and Surveillance Concept

Multifaceted, Interrelated Set of Technologies which Combine to Provide the Required Service Life Prediction Capability



Aging and Surveillance
Milestones



Aging and Surveillance
A&S Programs/Objectives

- **Program Management Is a Cooperative Effort Between Both the Air Force and Navy**
- **Three A&S Programs Developed to Address Needs**
  - **Service Life Prediction Technology**
  - **NDE Data Processing**
  - **Critical Defect Assessment**
- **Objectives**
  - **Reduce Level of Uncertainty in Determining Service Life of Rocket Motors**
    - Reduce uncertainty in predicting stresses and strains
    - Reduce material characterization uncertainties
    - Reduce aging model uncertainties

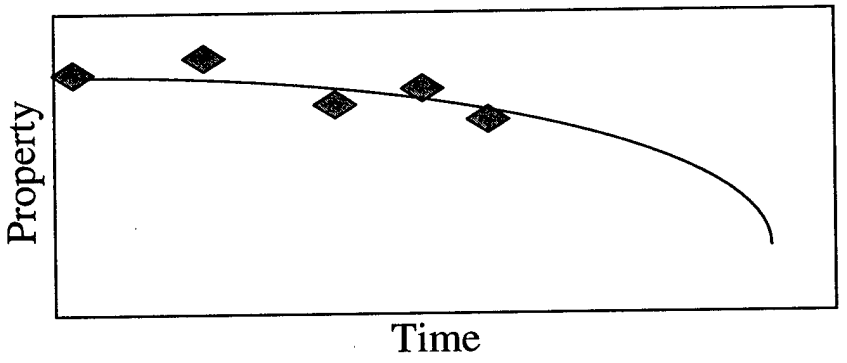
Service Life Prediction Technology Program

Aging and Surveillance
SLPT Philosophy

- **Move from Empirical to Mechanistic Approach to Predict Service Life**

EMPIRICAL:

1. **Gather trend data.**
2. **Fit to a function.**
3. **Extrapolate.**



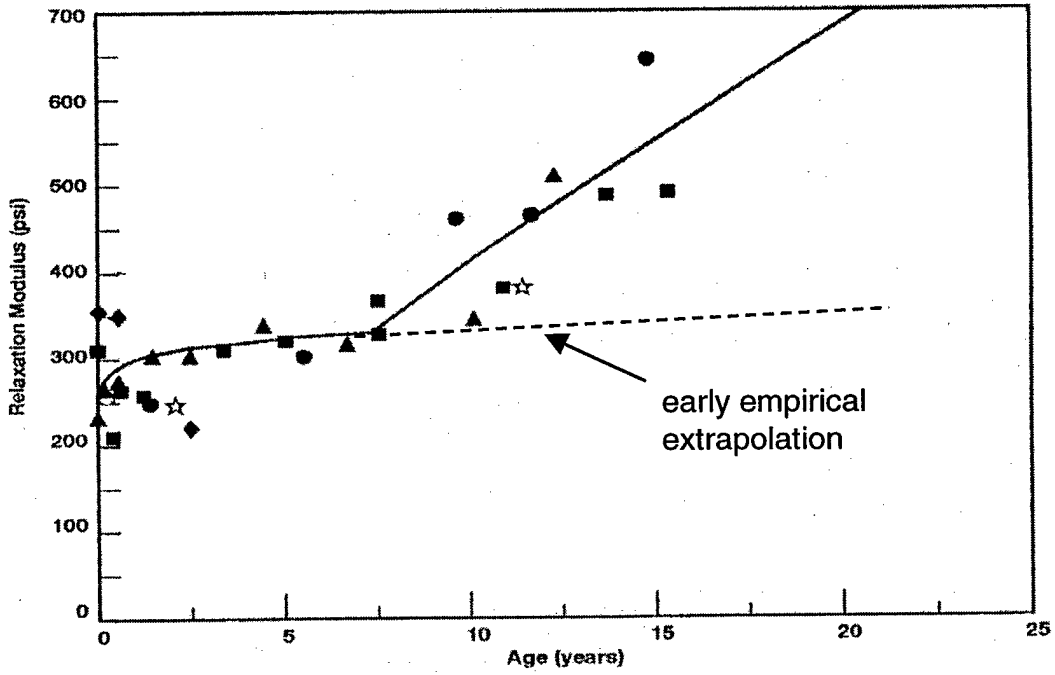
MECHANISTIC **(based on actual science of aging):**

1. **Define principal chemical mechanisms of aging.**
2. **Measure associated diffusion/reaction parameters.**
3. **Predict future chemical state via chemical kinetics equations.**
4. **Link chemical state to mechanical state via microstructure.**
5. **Use mechanical state in FE code to predict motor response.**

Monitor all steps with relevant NDE.

Service Life Prediction Technology
Philosophy (cont.)

- **Example of Empirical Short Fall**

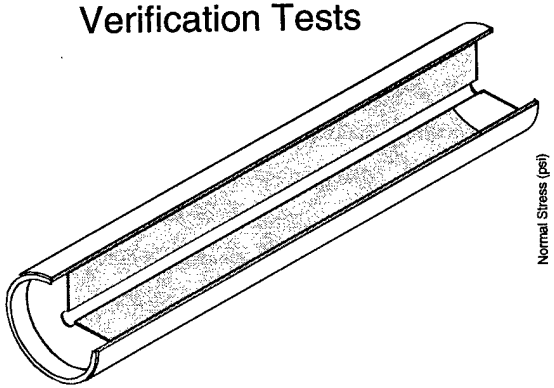


- ***Years of Aging Surveillance is Evolving from Empirical to Mechanistic Approaches***

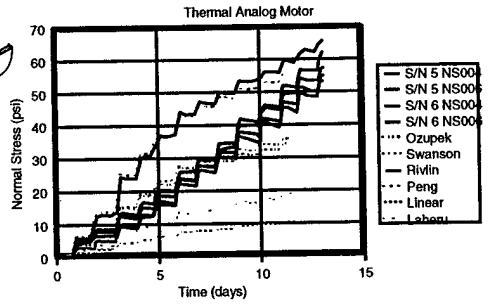
Service Life Prediction Technology
Program Emphasis

- **Investigation and Implementation of Nonlinear Constitutive Laws**
  - **Nonlinear Viscoelastic (NLVE) Material Model**
  - **Standardize Characterization Methods for Mechanical and Failure Properties**

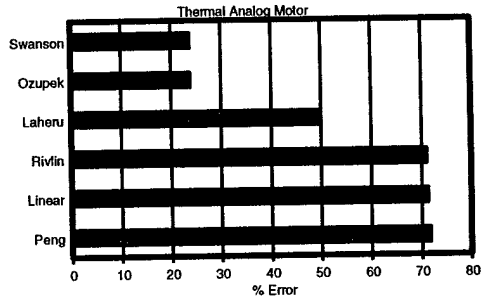
Verification Tests



Test Data & Analytical Predictions



Comparison of Predictive Error



Current NLVE Models are a great improvement over linear elasticity, but still have substantial error.

Service Life Prediction Technology
Program Emphasis (cont)

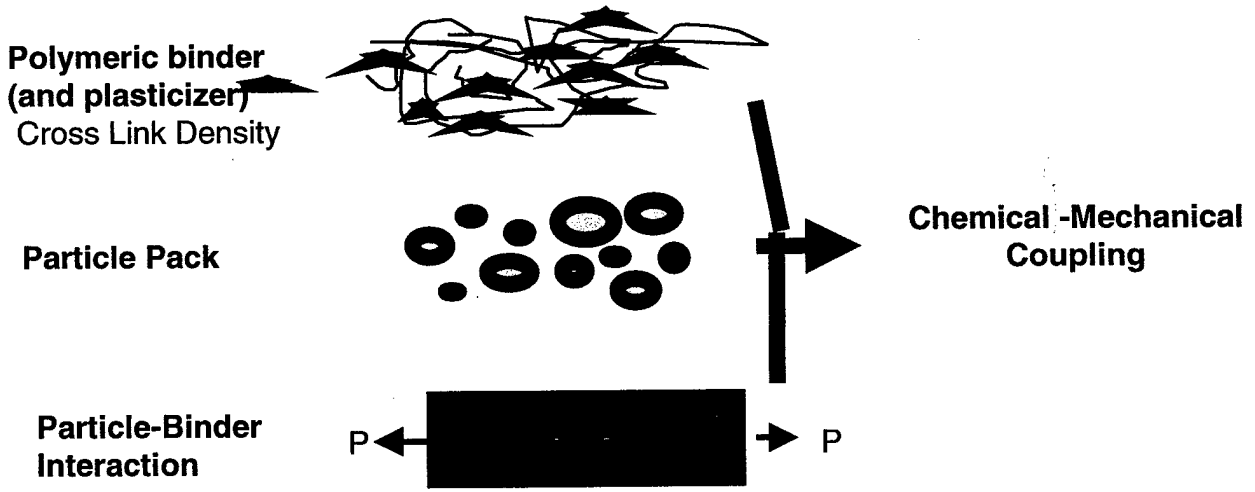
- **NDE Processes for Extracting Propellant Grain Material Properties**
  - **Downselect at least two NDE Methods for development**

- **Mechanical / Physical**
  - Ultrasonics
    - Elastic properties
    - Microstructural properties (e.g. particle pack, porosity, gradients)
  - High Res. 3-D X-Ray CT
    - Density profile
  - Mechanical hardness testers
    - Elastic, relaxation properties
  - Ultrasonic PVDF sensors
    - bulk response properties
  - Mechanical Sensors

- **Chemical**
  - IR, NIR, UV/VIS, RAMAN Spectroscopy
    - Composition
  - UV fluorescence
    - Composition
  - Solid State NMR
    - Changes in polymer network
  - Microwaves
    - Dielectric properties (viscosity and composition)
  - UV/VIS, fluorescence, RAMAN fiber optic sensors
  - Dielectric sensors

Service Life Prediction Technology
Program Emphasis (cont.)

- **Modeling and Characterization of Chemical Migration and Reaction of Aging Propellants and Bondlines**
  - **Chemical aging mechanisms**
  - **Chemical-Mechanical Link**



With an eye toward the consolidation of constructs into constitutive theory

Form of the microstructural constitutive relation

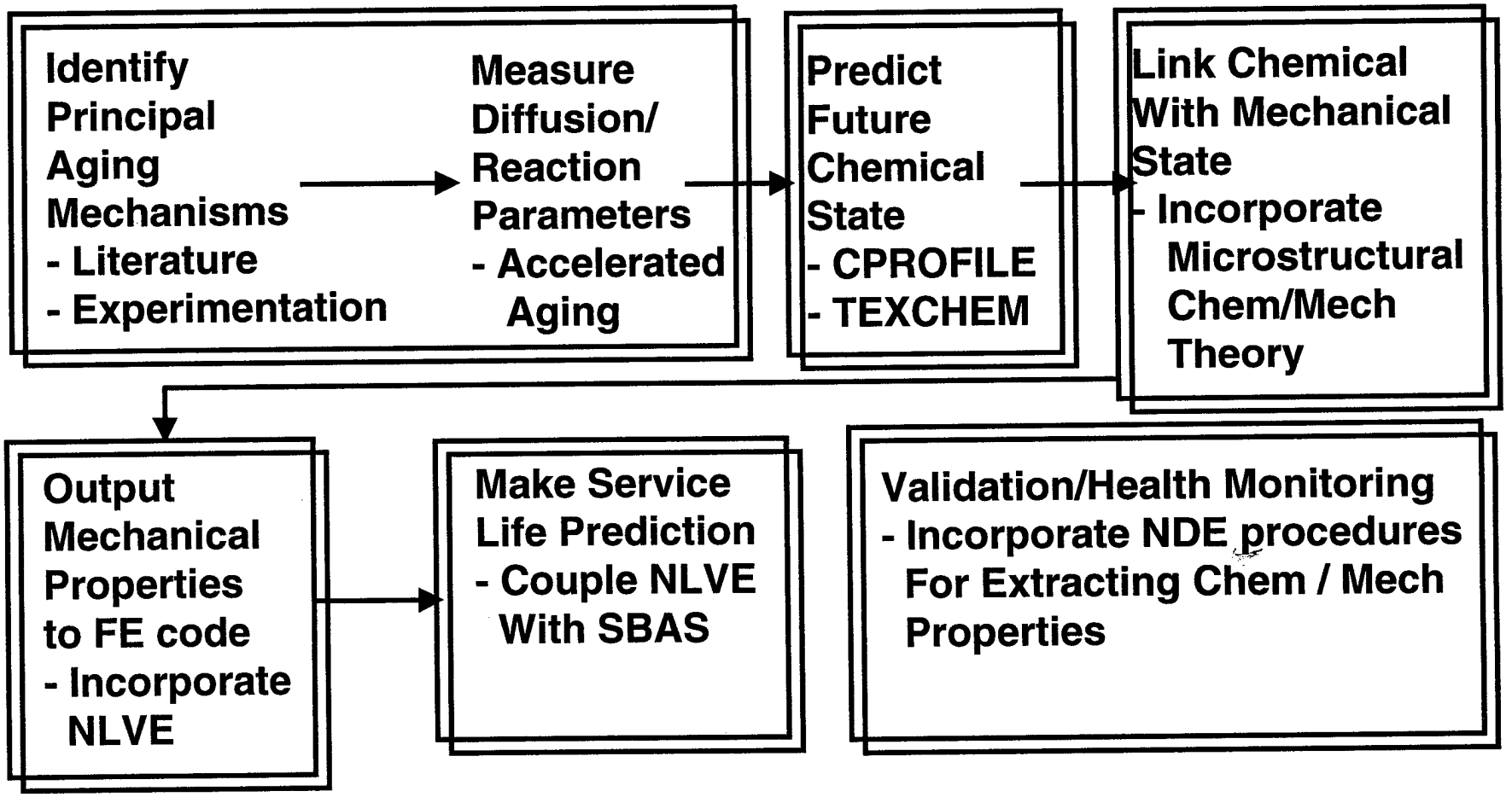
$$\begin{pmatrix} T_{11} \\ T_{22} \\ T_{33} \\ T_{23} \\ T_{13} \\ T_{12} \end{pmatrix} = \begin{pmatrix} c_{11} & c_{12} & c_{13} & c_{14} & c_{15} & c_{16} \\ c_{12} & c_{22} & c_{23} & c_{24} & c_{25} & c_{26} \\ c_{13} & c_{23} & c_{33} & c_{34} & c_{35} & c_{36} \\ c_{14} & c_{24} & c_{34} & c_{44} & c_{45} & c_{46} \\ c_{15} & c_{25} & c_{35} & c_{45} & c_{55} & c_{56} \\ c_{16} & c_{26} & c_{36} & c_{46} & c_{56} & c_{66} \end{pmatrix} \begin{pmatrix} E_{11} \\ E_{22} \\ E_{33} \\ 2E_{23} \\ 2E_{13} \\ 2E_{12} \end{pmatrix}$$

where $c_{ij} = c_{ij}^{matrix} + c_{ij}^{particles} = c_{ij}(\mathbf{E}(t), T(t), aging)$

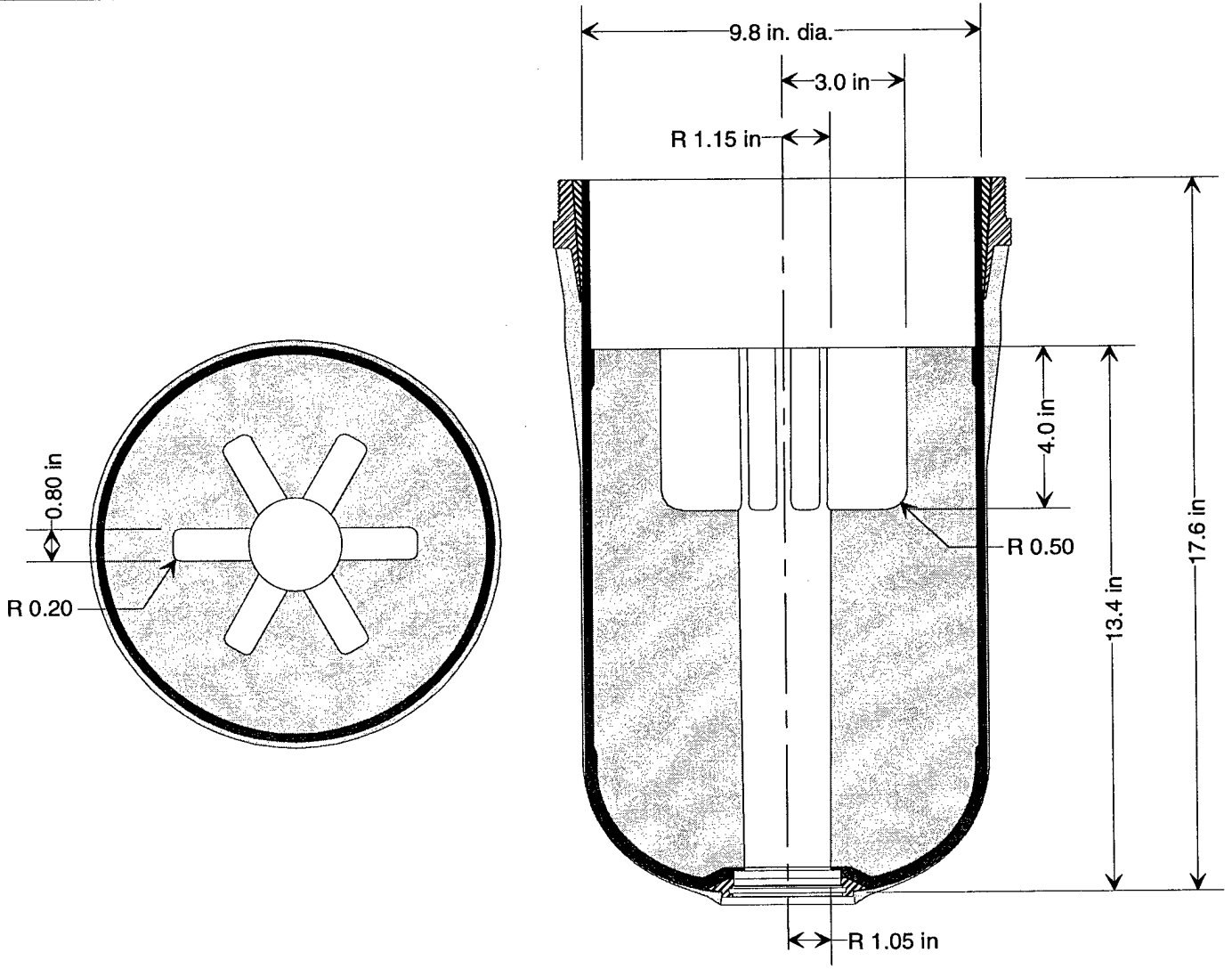
via ensemble averaging over the microstructure.

Service Life Prediction Technology
Philosophy (cont.)

Proposed Mechanistic Approach



Composite Case Analog Aging Motor

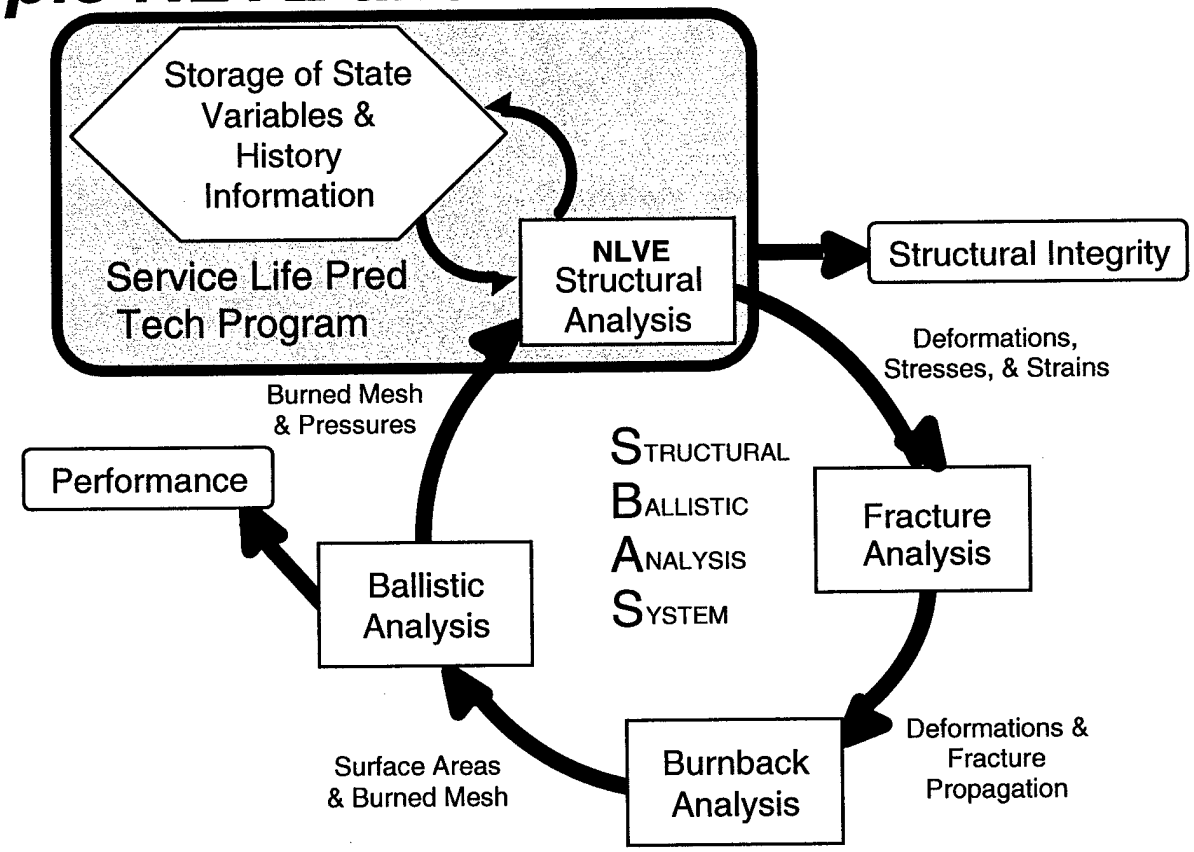


Aging and Surveillance
Service Life Prediction Technology

- **Service Life Prediction Technology (SLPT)**
  - ***TASK 1. PROPELLANT/BOND CONSTITUTIVE LAWS***
  - ***TASK 2. PROPELLANT / BONDLINE PROPERTIES FROM NDE***
  - ***TASK 3. AGING MECHANISMS FOR PROPELLANT/BONDLINES***
- **Three Propellant Systems to Be Investigated**
  - **HTPB, PBAN and High-Elongation**
- **SLPT Deliverables**
  - **Final Product = Mechanistic Approach to Service Life Prediction**
  - **Final Product = NDE Procedures**
  - **Integration of NLVE into Structural Ballistic Analysis System (SBAS-II)**

Service Life Prediction Technology
SBAS II

Couple NLVE and Ballistics Codes



Service Life Prediction Tech. Payoffs

- **Reducing Uncertainties in Service Life Prediction Increases Fidelity of Service Life Assessment**
  - Fewer aging assets required for aging surveillance programs
  - Increases interval between motor inspection,dissection and/or test firings to re-qualify motors
- **NDE Methods for Monitoring Chem./Mech. Properties of SRMs Allows Service Life Assessment on Individual Motors**
  - Does not destroy motor assets
  - Allows assessment of individual motor state rather than rely on population statistical analysis
    - Avoid premature replacement costs of aged assets

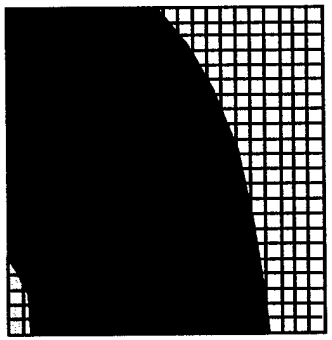
NDE Data Processing Program

NDE Data Processing Technology Objective/Approach

- **OBJECTIVE: Improve Automated NDE Data Processing Capabilities by 50%**
- **APPROACH: 1. Develop High Resolution CT System for Inspecting Interfaces in SRMs.**
  2. Add Capabilities to Recently Developed Automated NDE Data Processing System

1. Hi Resolution X-ray CT for Interfaces

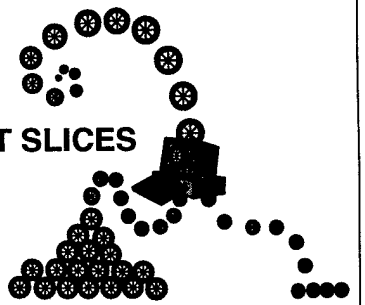
Typical CT Resolution
- 40 mils/Pixel at Case Wall MM Stg 3
- Need 3 Pixels for Proper Detection



High Resolution
- 3-5 mils Resolution
- Detect Features 10mils in Width

2. Automate NDE Data Processing

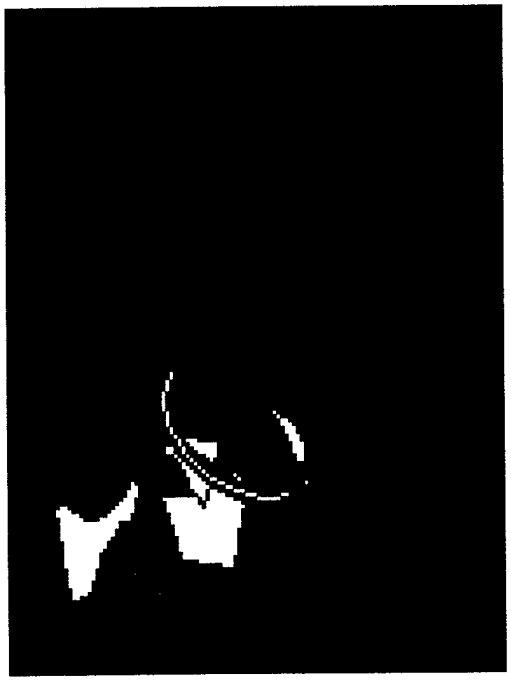
Current Procedure



PASS FAIL

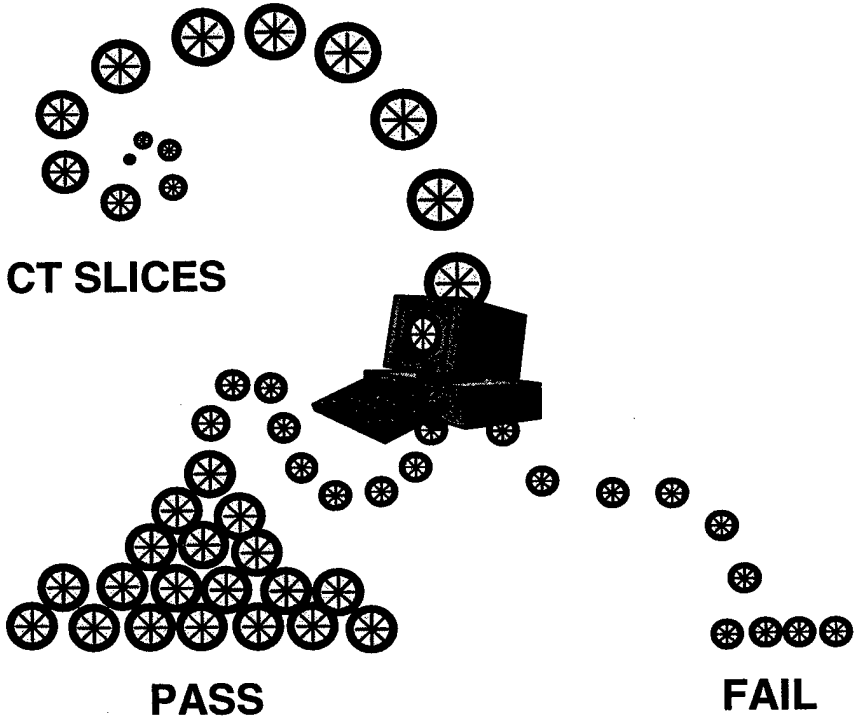
Aging and Surveillance
NDE Data Processing Technology

Automation of NDE Data Processing



Current Procedure

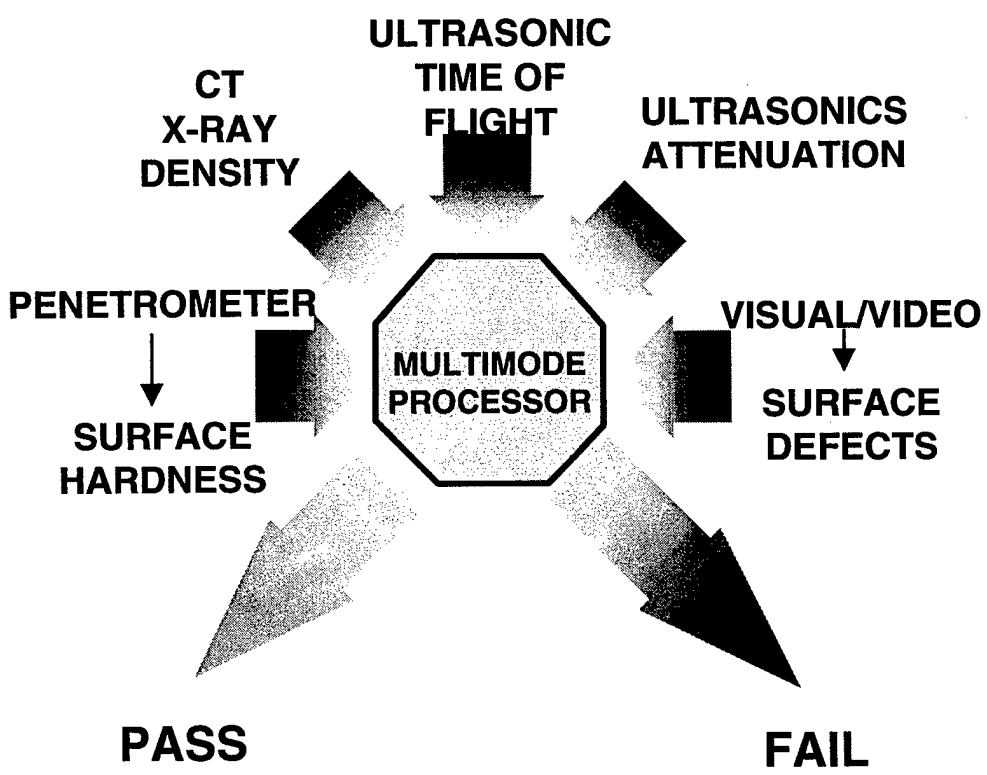
Manual Review of All Images



- Automate Processing of Images
- Focus Manual Review on Failed Images

Aging and Surveillance
NDE Data Processing Technology

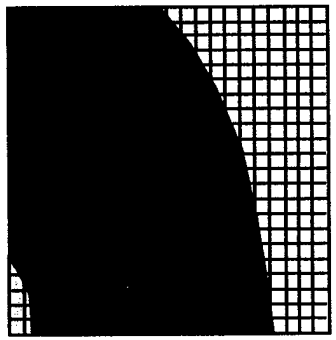
NDE Multi-mode Data Processing



- Each Data Mode has Strengths and Weaknesses
- Combining Modes Will Increase Reliability of Automated Feature Detection and Processing

Hi Resolution X-ray CT for Interfaces

Typical CT Resolution
- 40 mils/Pixel at Case Wall MM Stg 3
- Need 3 Pixels for Proper Detection



High Resolution
- 3-5 mils Resolution
- Detect Features 10mils in Width

Aging and Surveillance NDE Data Processing Tech

- **NDE Data Processing Technology (NDEDPT)**
  - **Task 1, High Resolution 3D Computed Tomography**
  - **TASK 2. Automated Case Damage Assessment System**
    - Define Requirements and Develop Specifications for System to Detect and Assess Damage in Composite Motor Cases
    - Effort is being Reassessed due to New Activities in This Technology Area Jointly Chaired by Aerospace Corporation and AFRL
  - **TASK 3. Automated NDE Data Processing**
    - Extend Development of Automated NDE Data Evaluation System (ANDES) Currently in Operation at Hill AFB

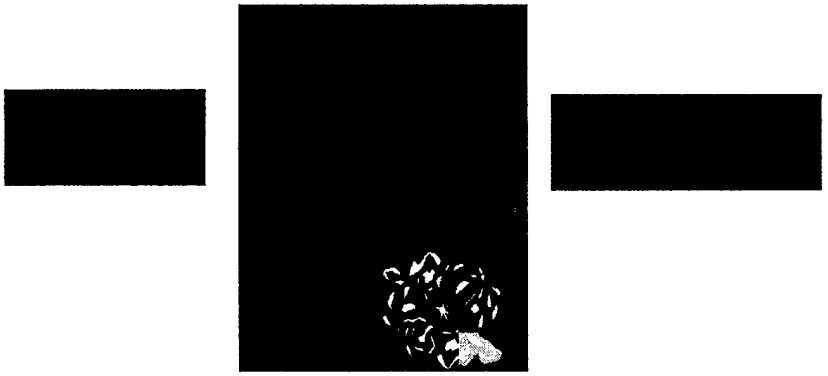
NDE Data Processing Technology Payoffs

- **Improved High Resolution CT Systems Increases Ability to Assess State of SRMs.**
  - Better resolution on as-built conditions
  - Anomalies better defined particularly along bondlines
- **Increased Automated NDE Data Processing Capabilities Will Reduce Manual Inspection Costs by 50%.**
  - Reduce the number of man-hours required to inspect individual CT data slices.
  - Quicker response time to defect assessment

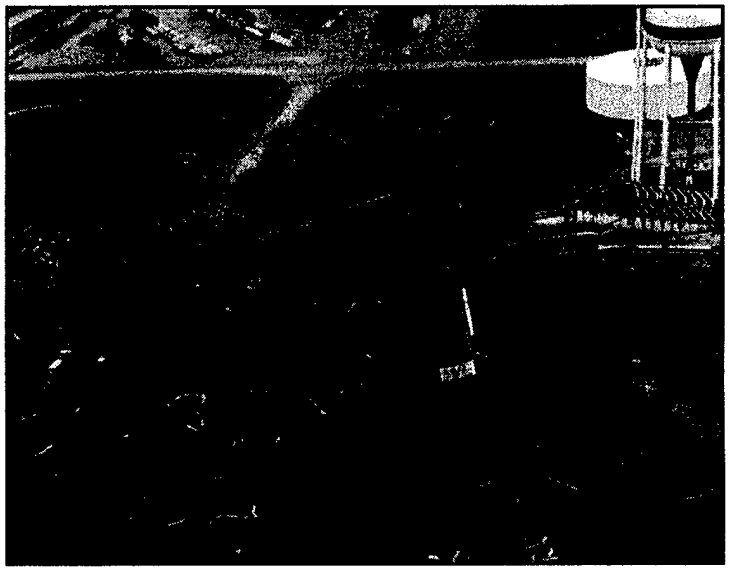
Critical Defect Assessment Technology Program

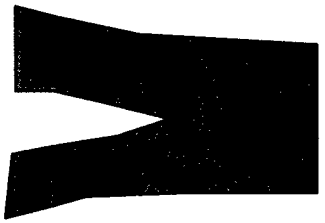
Aging and Surveillance
Critical Defect Assessment

Structural Ballistic Interaction



Bondline Separation





Bi Material Fracture Mechanics

Aging and Surveillance
Conclusions

- **A&S programs developed based on input from the services and industry**
- **Goal is to extend the state of the art in rocket motor analysis**
- **Developing tools for true predictive abilities and automated analysis techniques**
- **Tools/technology developed have a wide range of applications**